

Volume, heat and salt transport in the North-Eastern Bering Sea during 2007-2010 derived through the 4dvar data assimilation of in-situ and satellite observations

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1-IARC, UAF, 2-APL UW, 3-COAS UO, 4-UAF

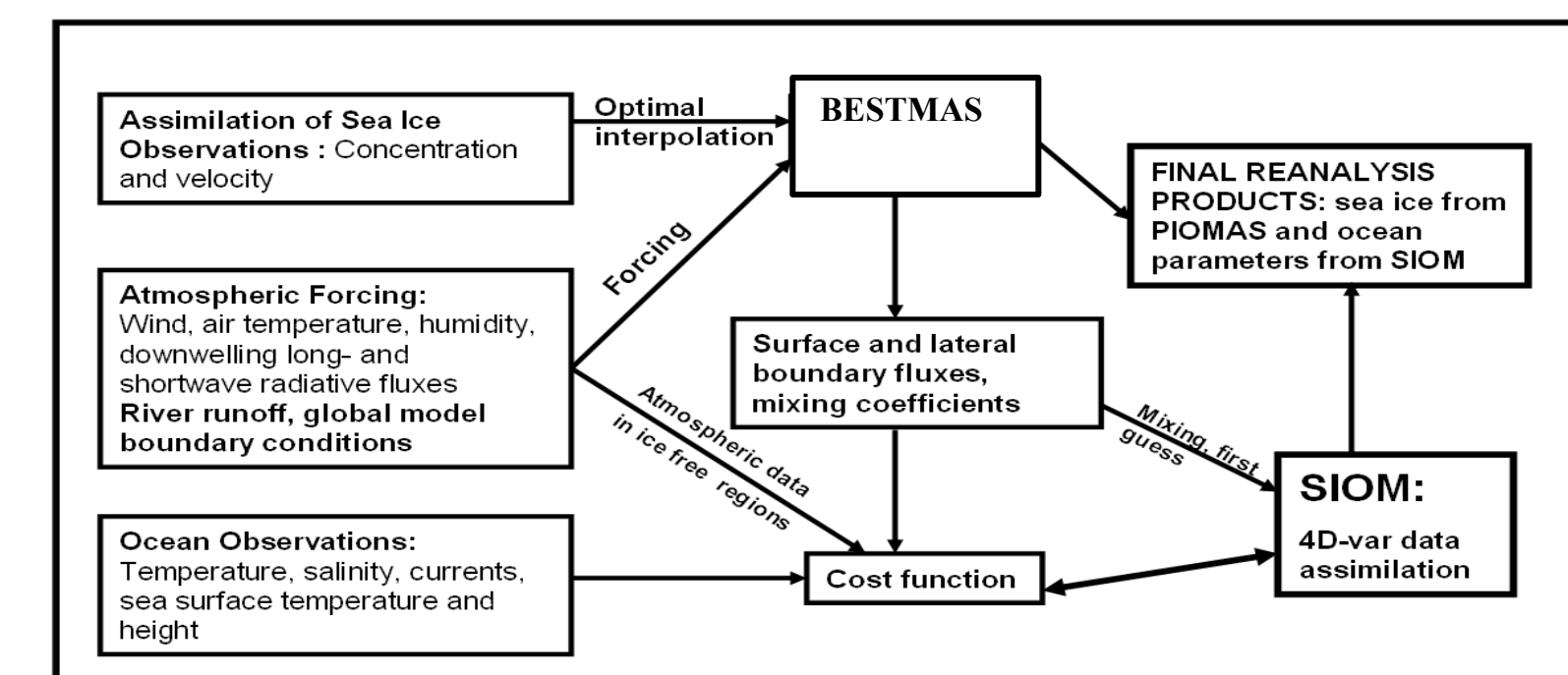
Motivations

The rich collection of BEST-BSIERP observations and other sources of data provide an excellent opportunity for synthesis through modeling and data assimilation to improve our understanding of changes in physical forcings of the Bering ecosystem in response to climate change. Assimilating data of different origins, which may be sparse in space and time, is difficult using simple algorithms (traditional optimal interpolation, correlation analysis etc.). The 4Dvar approach is effective for performing spatiotemporal interpolation of sparse data via interpolation (covariance) functions with scales based on ocean dynamics (Bennett, 2002).

Objectives:

- To develop 4Dvar data assimilation system for the Eastern Bering Sea and reconstruct circulation during 2007-2010
- To analyze volume, heat, and salt transport in the Eastern Bering Sea, conduct particle study, and define the areas with maximum retention.
- To conduct adjoint sensitivity analysis with the goal of optimizing observational programs in the area.

4Dvar data assimilation system combined with BESTMAS output



The nested data assimilation system is built using the following data assimilation components:

Forward Model: the model is a modification of the OGCM designed by Madec et al., 1999. The numerical scheme of the model is implicit for both barotropic and baroclinic modes (Nechaev et al., 2005, Pantelev et al., 2006). The Coriolis terms in the momentum equation are approximated with implicit scheme (Nechaev and Yaremchuk, 2004).

Adjoint Model: analytical transposition of the operator of the tangent linear model.

Control vector: initial conditions (SSH, T/S, U/V), boundary conditions (T/S, U/V, surface heat/salt fluxes, wind stresses). Time evolution of the functions representing boundary conditions is approximated by piece-wise linear continuous polynomials on 7-day intervals.

Coarse resolution (CR) model is configured in the region shown in Figure 1 on a grid with a spatial resolution 20x20km, 37 non-uniform levels with 3m resolution at the surface and 20m near the bottom shelf), and time step 0.1 days.

Data assimilation time window – 3 months

Fine resolution (FR) model is configured in the region shown in Figure 1 on a grid with a resolution 8x8 km and the same vertical resolution as CR model. Time step – 0.04 days.

Data assimilation time window – 1 month.

Motivation for developing a nested 4Dvar data assimilation system

Two-way variational nested data assimilation system is a straightforward approach to resolve common contradictions between the requirements imposed on the design of the system:

- To maintain a proper resolution of complicated bottom topography and coastline configuration in the key dynamical regions;
- To keep the dimension of the data assimilation problem reasonably small for numerical efficiency;
- To account for dramatic differences in data coverage density over the region of investigation, and
- To reduce the ratio of the number of degrees of freedom within the data assimilation system and the number of the observations, without significantly simplifying the model physics.

Nested variational data assimilation system

The presented results are obtained with “*weakly two-way nested*” variational algorithm. The first-guess solution for the nested data assimilation system is specified as an optimal CR solution resulting from application of a conventional 4Dvar procedure to the CR model and a solution of the FR model obtained in a one-way nested model run. Optimization of the CR and FR model control parameters is performed by the repeated solution of the two (CR and FR) 4Dvar problems. The cost functions for CR and FR 4Dvar problems have similar structures, containing two fundamental types of terms: one penalizing the model misfits with observations, and the so-called “background” terms penalizing the model misfits with additional (e.g. climatological) data. The *two-way* information flow between CR and FR data assimilation solutions is conducted by including the CR solution as background data in the FR cost function and vice versa.

Approximate computational time: 3x2*10,000 years

We succeeded to conduct 3 outer iterations within the Nested Data Assimilation System. Each iteration includes approximately 500-600 runs of the forward and adjoint CR and HR models, and an adjoint model run is usually 4-5 times longer. Thus, the reconstruction of the circulation during *one/four* year is equivalent to 2x2,500/2x10,000 years of the forward CR and HR models run.

Data:

- Time series of velocity, T/S data from moorings in the Bering Strait and N55,40,25, C55,C40,C25 and S55,S40,S25
- T/S data from all hydrological surveys
- Satellite SSH observation referenced to the high resolution MDOT (Pantelev et al., 2009)
- Surface drifters observations
- Realistic (NCEP/NCAR) wind stresses and heat/freshwater surface fluxes.
- OSTIA SST
- Ice concentration

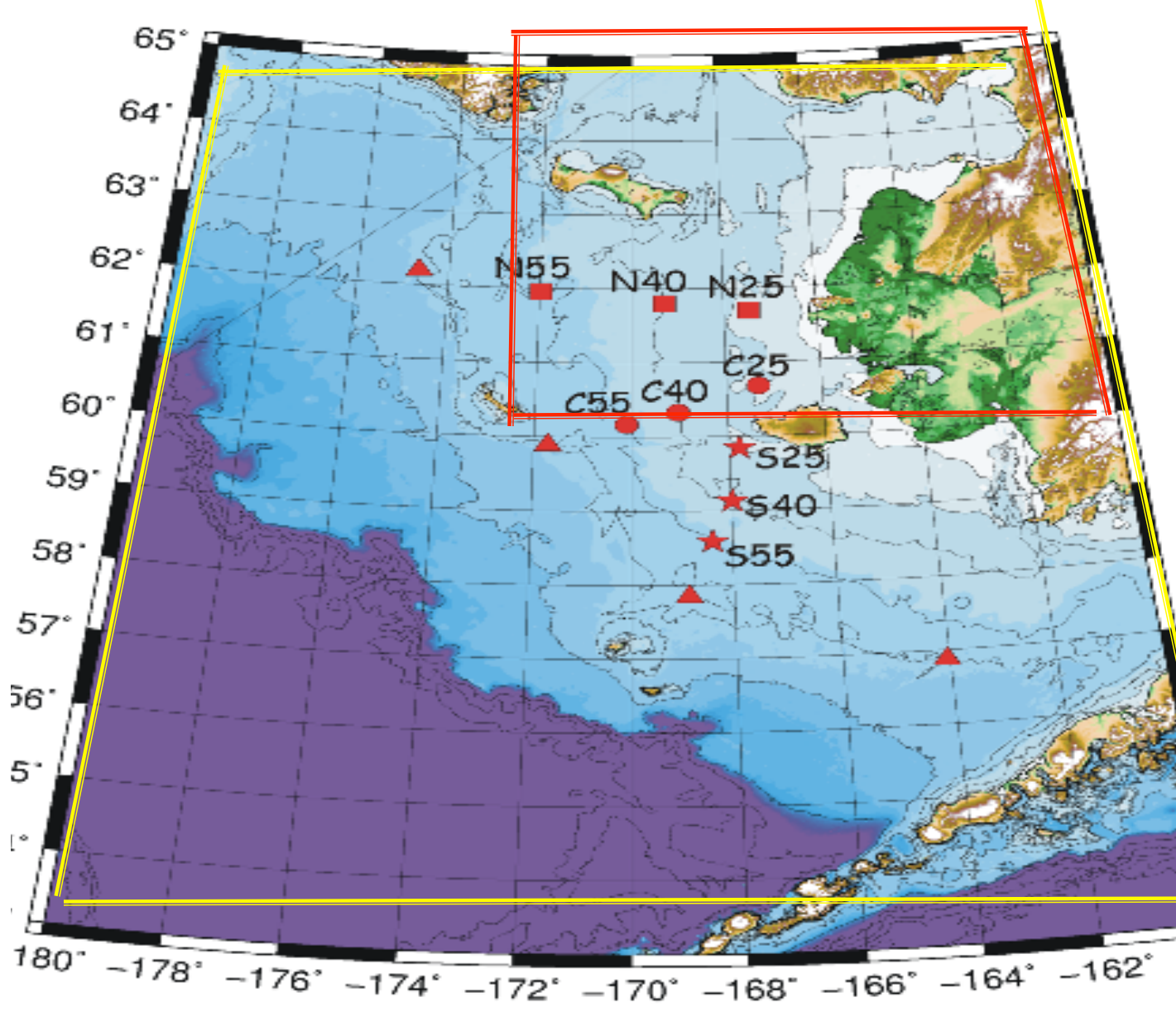


Figure 1 Location of the BEST moorings and approximate boundaries of the coarse resolution (yellow) and high resolution (red) model domains.

Quality of the reconstruction: model-data agreement

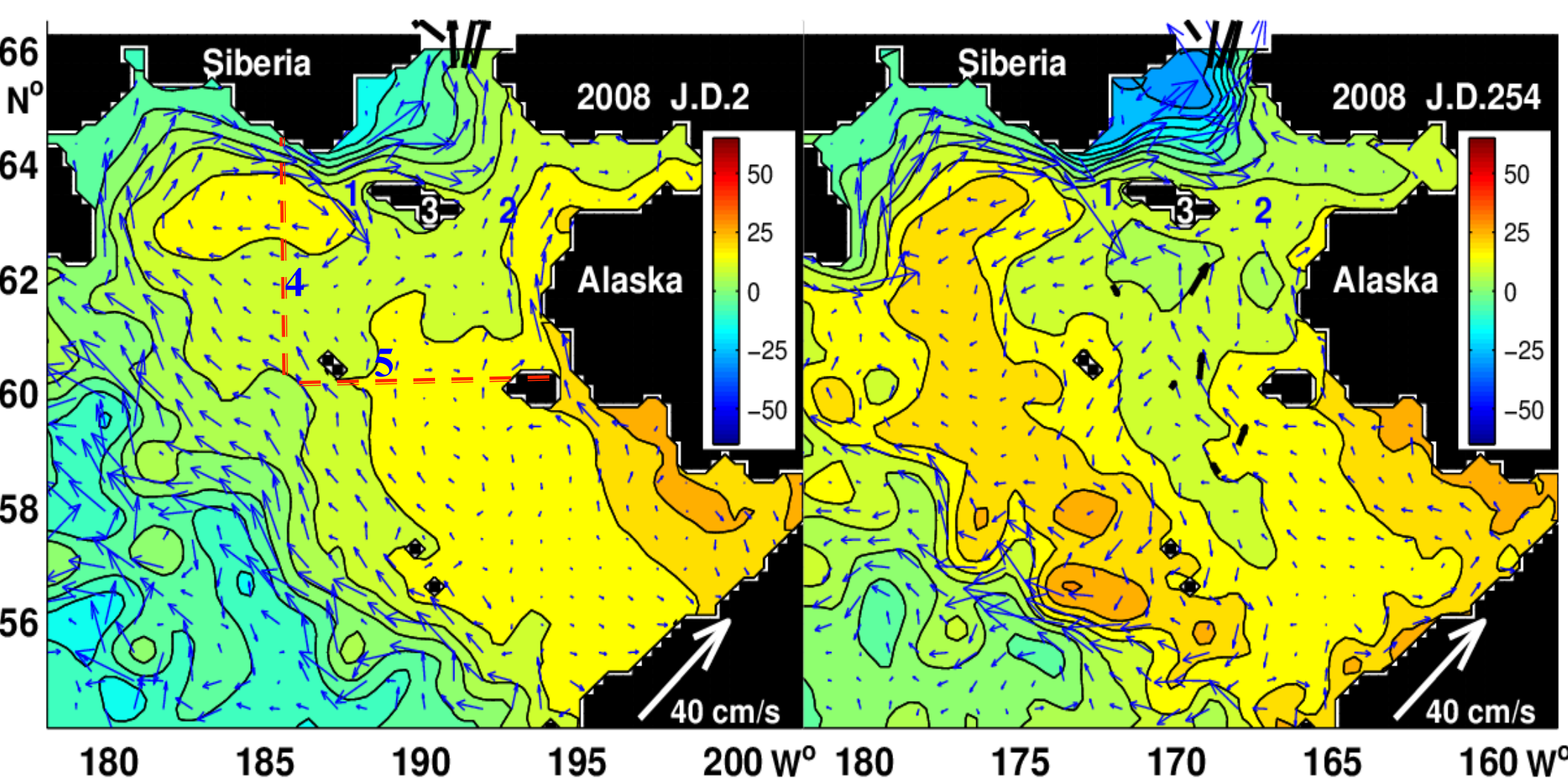


Figure 2 Snapshots of reconstructed sea surface height (cm) and surface circulations in the Bering Sea in 2008 (2 Jan. – left; 10 Sept. – right). Thicker black arrows designate the locations of the moorings in the Bering Strait and the Eastern Bering Sea shelf. Numbers 1,2,4,5 designate the Anadyr and Spanber straits and western and southern sections utilized for analysis of the volume heat and salt fluxes (Figure 3). Number 3 – designate St. Lawrence Island. Relative model-data errors in vertically averaged velocities and absolute SSH ranges between 0.1-0.3 and 0.2-0.4 respectively

Figure 3. Volume, heat and, salt transports through five sections in the Northern Bering Sea

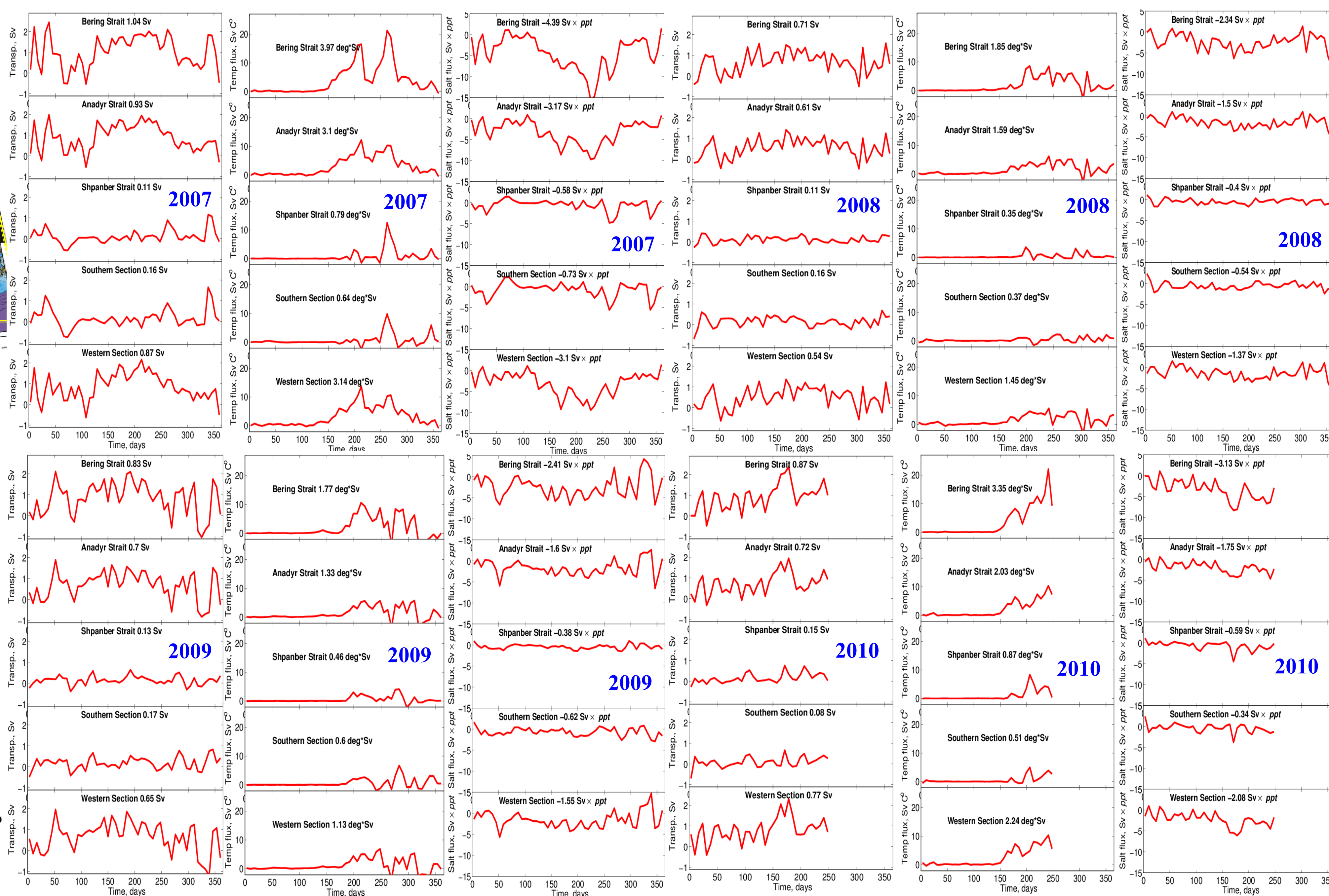
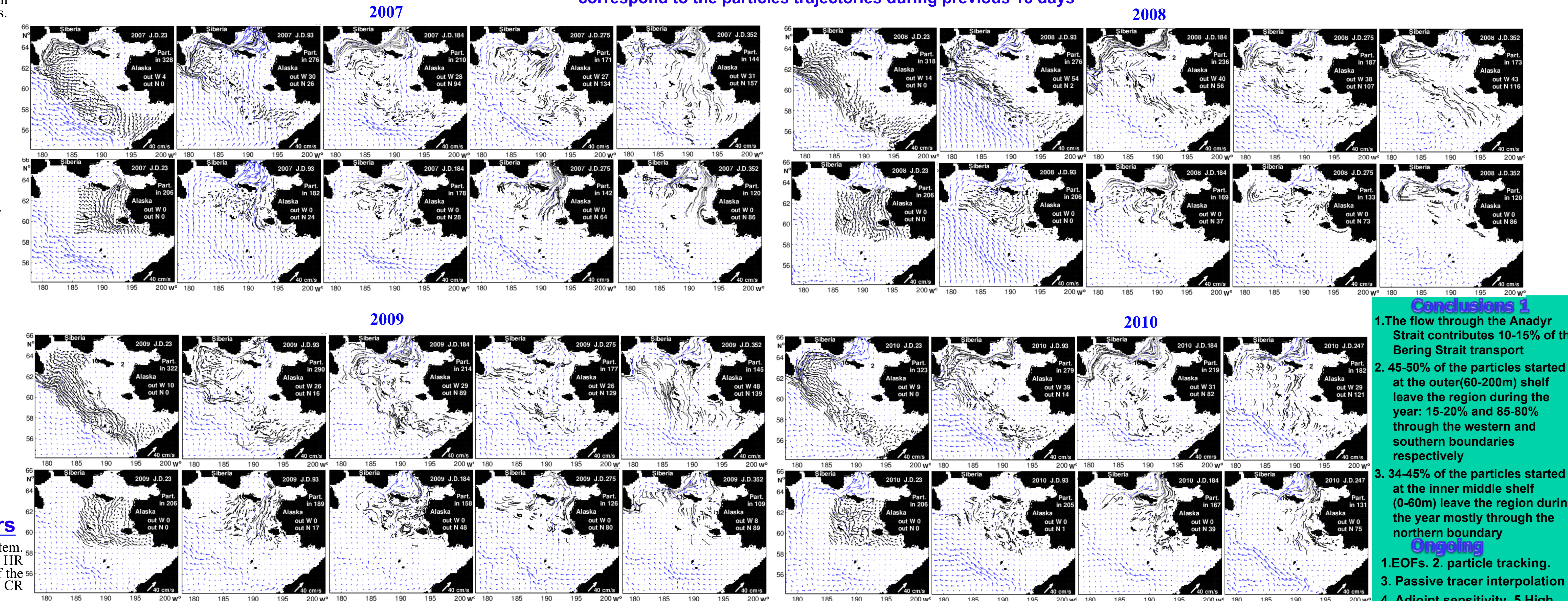


Figure 4. Particle trajectories for 2007-2010 started near the shelf break (60-200m) and in the internal shelf. The numbers of particles within domain and particles leaving through the western and northern boundaries are shown. Particle tails correspond to the particles trajectories during previous 15 days



Conclusions 1

- The flow through the Anadyr Strait contributes 10-15% of the Bering Strait transport
- 45-50% of the particles started at the outer(60-200m) shelf leave the region during the year: 15-20% and 85-80% through the western and southern boundaries respectively
- 34-45% of the particles started at the inner middle shelf (0-60m) leave the region during the year mostly through the northern boundary

Ongoing

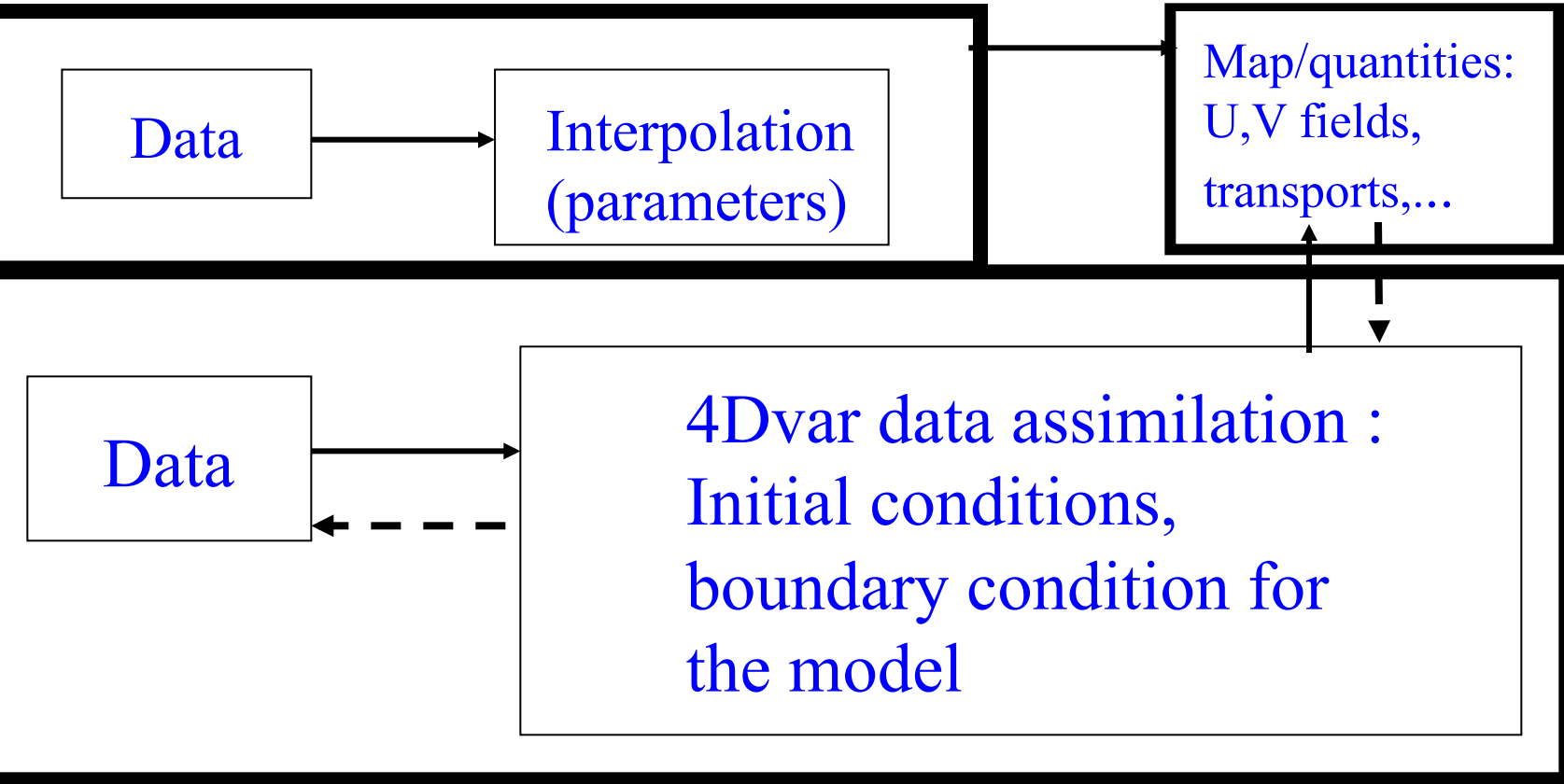
- EOFs. 2. particle tracking.
- Passive tracer interpolation
- Adjoint sensitivity. 5.High resolution domain

Optimization of High Frequency Radars in the Northern Bering Sea

Objectives

- to explore feasibility of using the Arctic Cup NFS ensemble for assessing model error statistics in the Bering Strait region
- evaluate performance of the adjoint sensitivity technique
- optimize position of an HFR pair with respect to most accurate estimation of the mass, heat and salt fluxes through 7 key sections in the region

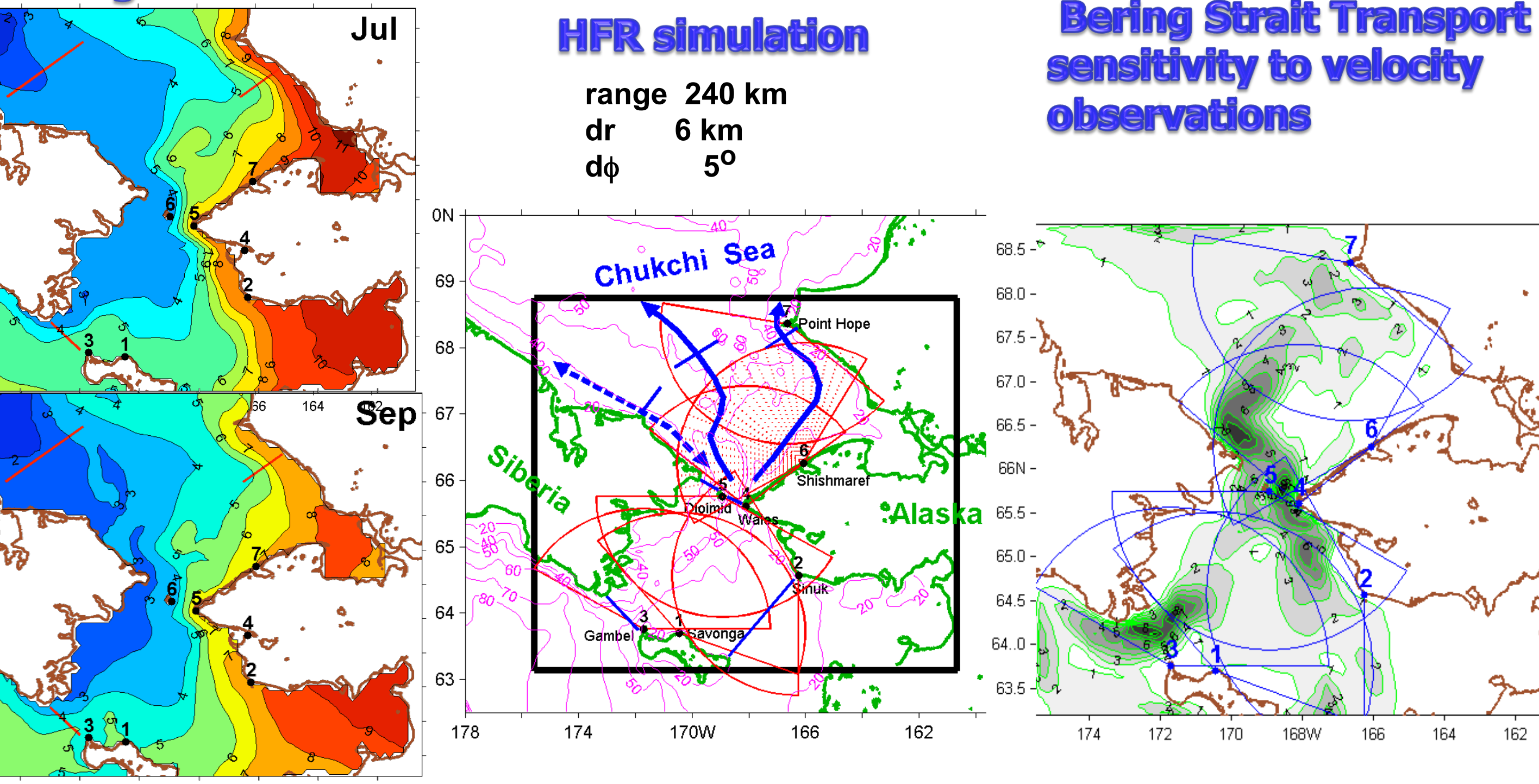
Schematic of the adjoint sensitivity approach



What kind of data cause the major changes in the “map”?

Inverse model:
SIOM, 3 km, 3 months
Assimilated data: 2M profiles, SSH
Bering Strait transport: 0.95 ± 0.08 Sv

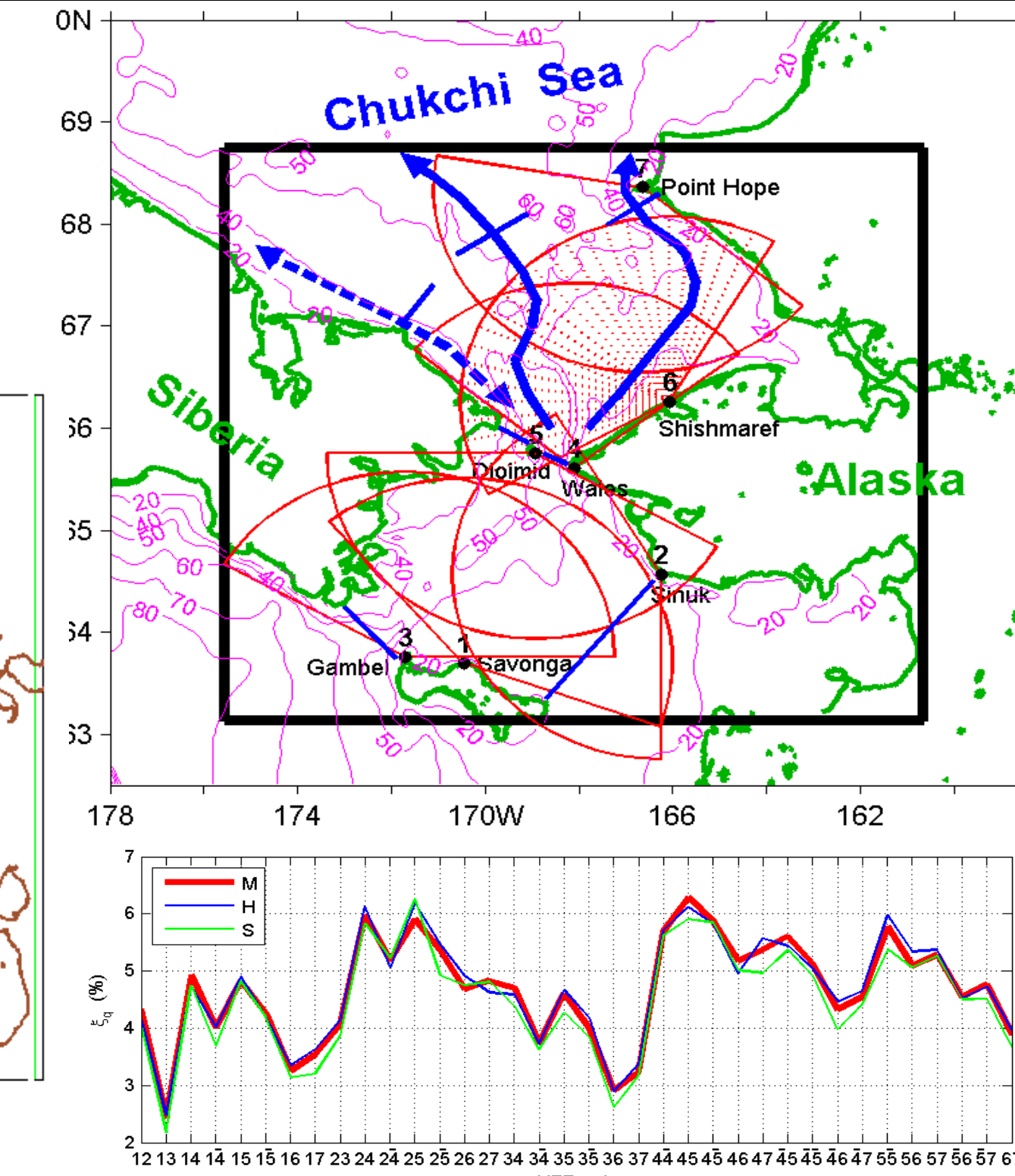
Background state



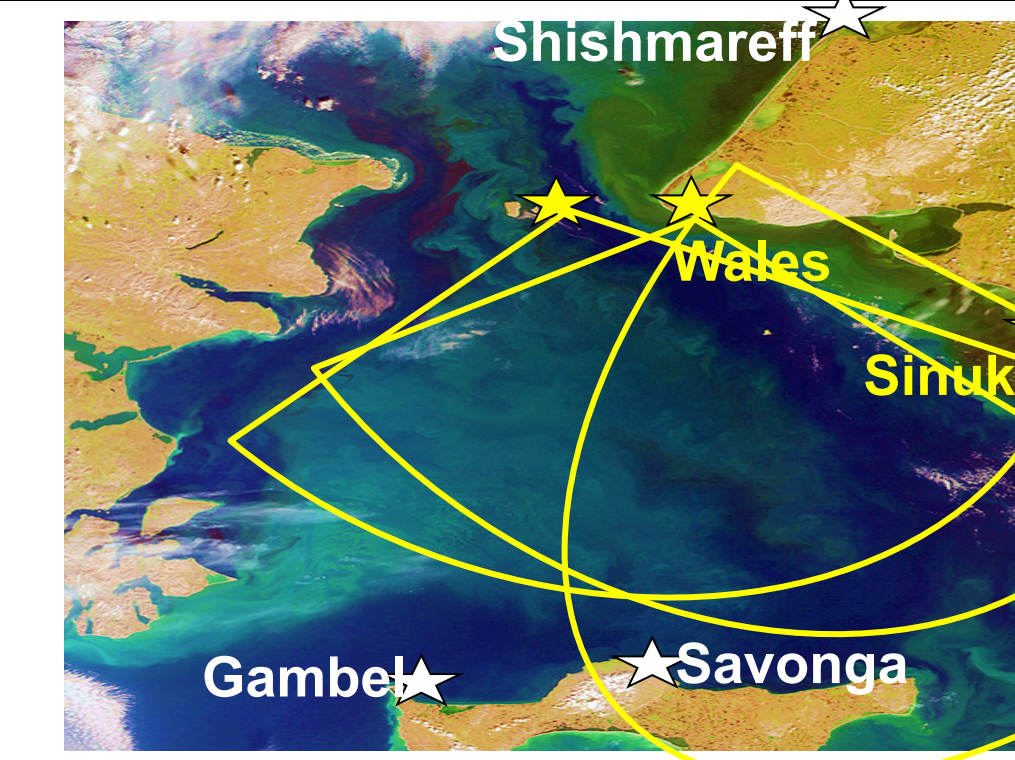
HFR simulation

range 240 km
dr 6 km
dφ 5°

Bering Strait Transport sensitivity to velocity observations



Results



Conclusions 2

- Optimal locations are in Diomide, Wales, and Sinuk (depend on the target quantities)
- Sinuk location provides the largest error reduction in heat and salt fluxes
- Optimal location for observation of the Bering Strait transport from ONE mooring is in the American Part of the Bering Strait